Response-mediated spatial priming despite perfectly valid target location cues and intervening response events

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ABSTRACT

Attentional effects are often inferred from keypress reaction time (RT) studies when two sequentially presented stimuli, appearing at the same location, generate costs or benefits. The universality of these attentional attributions is challenged by data from perceptual discrimination tasks, which reveal that location repetition benefits and costs depend on whether a prior response repeats or switches, respectively. According to dual-stage accounts, these post-attentional effects may be abolished by making responses in between two target stimuli or by increasing target location certainty, leaving only attentional effects. Here, we test these accounts by requiring responses to stimuli in between targets and by increasing target location certainty with 100% valid location cues. Contrary to expectations, there was no discernible effect of cueing on any repetition effects, although the intervening response diminished stimulus-response repetition effects while subtly reducing location-response repetition effects. Despite this, there was little unambiguous evidence of attentional effects independent of responding. Taken together, the results further highlight the robustness of location-response repetition effects in perceptual discrimination tasks, which challenge whether there are enduring attentional effects in this paradigm.

Spadaro, He and Milliken (2012; see also Spadaro & Milliken, 2013) have put forward a sublimely simple method that has some significant implications for the typical sequencing effects found in the common two-alternative forced choice (2-AFC) tasks in the visual cognition literature. Across a number of experiments, Spadaro et al. demonstrated that making any response to any stimulus in between serially presented target stimuli, whose features (e.g., color) had to be discriminated with button presses, reverses the classic stimulus-response repetition effect (e.g., Pashler & Baylis, 1991). By stimulus-response repetition effect, we refer to the commonly reported finding of faster RTs when both an earlier target stimulus and response repeat, instead of switch, some time later. In Spadaro et al's special case, if any stimulus and response intervenes between two target stimuli, RTs are slower when both target stimulus and response repeat, instead of switch, sometime later. Spadaro et al.'s preferred theory is that the intervening stimulus and response disrupt the link in memory between the prior stimulus and its response, thereby unmasking attentional, stimulus-only, priming effects (e.g., non-spatial inhibition of return; Law, Pratt & Abrams, 1995).

Although Spadaro and colleagues (Spadaro et al., 2012; Spadaro & Milliken, 2013) had a more local focus, their basic finding has the possibility to be a major theoretical advance in visual cognition. Many literatures that study how attention is primed from one moment to the next now recognize that a number of RT patterns are more representative of memory retrieval and updating effects than attentional priming effects (e.g., Martin-Arevalo, Chica & Lupianez, 2013, in the spatial cueing literature; Gokce, Müller & Geyer, 2013, in the inter-trial spatial priming literature on visual search; and Frings, Schneider & Fox, 2015, for a review of prominent retrieval theories in the spatial negative priming literature). Because any method that promises to disrupt memory retrieval and updating whilst sparing attentional priming could help disentangle the two, the utility of the intervening response method deserves some serious consideration.

Providing some of this consideration, we (Hilchey, Rajsic, Huffman & Pratt, 2017) recently applied the intervening response event method to a variation on Posner's classic spatial cueing paradigm (Posner & Cohen, 1984), which is often considered a model task for studying the consequences of earlier attentional orienting on later attention. Before we describe this, a bit of background is required. In a classic variation of the spatial cueing task, a stimulus appears somewhere in peripheral vision whilst gaze remains fixed on a location; stimulus presence has to

be detected or localized (Posner, Cohen, Choate, Maylor & Hockey, 1984; Maylor & Hockey, 1985; Tassinari, Aglioti, Chelazzi, Marzi & Berlucchi, 1987). Shortly after (usually > 200 ms), a second stimulus appears randomly at the same or different location as the first. The basic finding is that RTs are slower when stimulus locations repeat as compared to switch. This effect is usually stable regardless of whether non-spatial stimulus features (e.g., color) repeat or switch (e.g., Kwak & Egeth, 1992; Tanaka & Shimojo, 1996; 2000; Fox & de Fockert, 2001; Taylor & Donnelley, 2002). These target location repetition effects, which are also presumed to be largely unrelated to whether a response is or is not made to the first stimulus (Welsh & Pratt, 2006; Maylor & Hockey, 1985), are considered the hallmark of spatial inhibition of return (IOR). Spatial IOR is often thought to reflect a bias against attending to previously attended regions (Posner, Rafal, Choate & Vaughan, 1985). In lesser-known variations of this task, the non-spatial features (e.g., color) of the targets are discriminated with arbitrary manual responses. Here there is little evidence of spatial or non-spatial IOR (e.g., Tanaka & Shimojo, 1996; Shimojo, Tanaka, Hikosaka & Miyauchi, 1996; Tanaka & Shimojo, 2000; Taylor & Donnelley, 2002). To account for the discrepancy between manual detection/localization and manual discrimination tasks, it has been suggested that spatial IOR is sometimes (e.g., in discrimination tasks) overshadowed by response repetition heuristics – which can be invoked by repeating the prior stimulus location (Hilchey, Rajsic, Huffman & Pratt, 2017) – when a current event matches a prior event in memory (Klein, 2004).

The main objective of Hilchey et al. (2017) was to apply Spadaro et al. (2012)'s intervening response method to a discrimination task in order to knock out the link in memory between the first target location and its response. In theory, this should abolish the tendency to re-enact the prior response when target locations repeat, thereby unmasking attentional, location-only, priming effects (e.g., spatial IOR, an inhibited location or object). To accomplish this, we used three possible target locations, one left of, one right of, and one at center fixation (Spadaro et al. only used center targets), at which to-be-discriminated colored stimuli randomly appeared, one after the other. In Experiment 1, two stimuli (e.g., red and blue) mapped onto each responding index finger, whereas in Experiment 2 a single stimulus mapped onto each responding index finger. Crucially, a white circle at fixation, which required a simultaneous response from both index fingers, always separated the target colors. Despite this intervening response event, there was no evidence of spatial IOR. Instead, typical response-mediated

location repetition effects were observed (see also Notebaert & Soetens, 2003; Rajsic, Bi & Wilson, 2014; as well as Hommel, Proctor & Vu, 2004, for discussion). That is, RTs were fastest whenever both the prior target location and response repeated or switched relative to when only the target location or response switched. This relationship was not significantly affected by whether the target color repeated; indeed, target color and location repetition did not appear to interact at all (see also Hommel, 1998; Colzato & Hommel, 2004). Simply put, when the location repeated there was a bias toward repeating the prior response and when the location switched there was a bias toward switching the prior response. As such, we refer to these findings as location-response repetition effects.

If the intervening event in Hilchey et al., (2017) was unable to instigate spatial IOR, perhaps it was able to generate non-spatial IOR (i.e., inhibited non-spatial features). In our Experiment 1, where there were 2:1 stimulus-response mappings, RTs were faster, not slower, for stimulus-response repeats regardless of whether location repeated. In Experiment 2, where there were 1:1 stimulus-response mappings, while RTs were overall slower for stimulus-response repeats than switches, RTs were never any slower for repeating than non-repeating stimuli when they appeared successively at the same location. Thus, there was nothing particularly compelling to suggest the presence of non-spatial IOR, especially when there were more than two target stimuli. These findings are in line with the historical data showing that a pure index of non-spatial IOR is difficult to obtain when multiple target locations are involved, and this is so with or without an intervening event. For example, Fox and de Fockert (2001) made similar observations in the context of simple stimulus detection tasks. Ultimately, non-spatial IOR is rarely observed when the task involves multiple target locations (Kwak & Egeth, 1992) and, even if it is, the effect is diminutive (Riggio, Patteri & Umilta, 2004).

So, why is it so difficult to observe attentional priming effects, like non-spatial or spatial IOR, in discrimination tasks when multiple possible target locations are involved? As we see it, one plausible reason is that there is a greater reliance on prior response-related memory representations when there is greater uncertainty about where or what the target will be. In essence, this proposal about target location ambiguity is conceptually similar to that found in the ‘dual-stage’ (Lamy, Yashar & Ruderman, 2010) account of inter-trial priming effects in visual search. Stated most generally, there may be a greater reliance on prior stimulus- and location-response representations as stimulus and location uncertainty increases (e.g., Olivers & Meeter,

2006) or, a bit more specifically, as search difficulty increases (Lamy, Zivony & Yashar, 2011; Yashar & Lamy, 2011). It is these stimulus-response or location-response representations that hypothetically overshadow attentional (stimulus-only or location-only) priming effects.

In the present report, we examine this uncertainty hypothesis by increasing target location certainty to 100% on select trials in Hilchey et al (2017)'s color-based 2-AFC task. To increase target location certainty, we applied a variation of a method used in the inter-trial priming literature to this task (e.g., Suzuki & Goolsby, 2001; Zehetleitner, Rangelov & Müller, 2012). On half of all trials, the target locations are precued with 100% validity by illuminating one of three marked locations 300 ms prior to target appearance. On the other half, all possible locations are illuminated, signaling that all three locations are equally likely to contain a target. In addition, there is an intervening response event (a white circle at fixation requiring a bimanual response) between targets on half of the trials to help unmask IOR effects, whether spatial or non-spatial (e.g., Spadaro et al., 2012). On predictive cue trials, the location of the intervening response event is also precued, in order to maximize location certainty during the trial. On trials without the predictive cues, all three locations are illuminated prior to the appearance of the intervening response event. This paradigm allows us to make several predictions. First, when target location certainty is low (equal across the three locations), we expect to find the usual location-response repetition effects regardless of the intervening response event, with little to no evidence of non-spatial or spatial IOR (i.e., Hilchey et al.). Second, following the uncertainty hypothesis, we expect that any location-response repetition effects and stimulus-response repetition effects should be abolished or greatly reduced when target location certainty is high (100%). Finally, with diminished location-response and stimulus-response repetition effects from the precue, the intervening event is expected to reveal attentional priming effects, spatial and/or non-spatial IOR, respectively.

METHODS

Participants

Twenty undergraduate students from the University of Toronto consented to participate for course credit. All were naive to the purposes of the experiment and reported normal or corrected-to-normal vision.

Stimuli and apparatus

Stimuli were displayed on the black background of 17" CRT monitor, which was connected to a Dell computer running custom Python software. Head position was stabilized with a chin and head rest 50 cm from the monitor. Responses were made on a standard QWERTY keyboard. The three possible target locations were marked by gray (RGB: 128, 128, 128) outline (1 pixel) placeholder boxes (2° x 2° of visual angle), one at center and one 7.5° left and right of center. The fixation cross (.15° x .15°) was displayed in white in the center placeholder box. Target stimuli were blue (RGB: 0, 0, 128) and green (RGB: 0, 128, 0) squares, which filled the placeholder boxes. Blue and green target stimuli were discriminated with 'z' and '/' keypresses, which were counterbalanced across participants. The intervening response event was a small white circle (radius = .3°) that was always centered in the middle placeholder, to which both keys were pressed simultaneously. Prior to the appearance of any target or intervening response events, either one or all three placeholder box outlines brightened (RGB: 255, 255, 255). The text at the end of each trial was displayed at the center of the monitor in white font.

Procedure

Sequences of possible trial events are illustrated in Figure 1. Each trial began with a fixation cross and three placeholder boxes; the fixation cross disappeared after 500 ms and another half second later the placeholder(s) increased in luminance. On half of all trials, each target location, including the intervening response event location if present (see below), was precued with 100% validity by the brightening of a placeholder box outline for 300 ms prior to target appearance (predictive cue condition). On the other half, all placeholder boxes brightened simultaneously for 300 ms prior to the appearance of each target stimulus, including the intervening response event, if present, indicating that all three locations were equally likely to contain a target stimulus (no cue/all cued condition). A target stimulus appeared in a brightened placeholder and remained onscreen until a response was made, at which point the placeholder(s) also returned to grey. On half of the trials (intervening event present condition), an intervening response event appeared 800 or 1000 ms after the first target stimulus. A bimanual response to this event extinguished it and the placeholder brightening. A second target stimulus appeared 800

ms later. On the other half of the trials (intervening event absent condition), there was no intervening response event; the second target stimulus appeared 1900-2100 ms after the response to the first. The response to the second target stimulus triggered a black screen for 750 ms if all trial responses were made correctly. If an error was made, an error feedback screen ("A response error was made...") appeared, which also included all of the response mappings for the task. This feedback was acknowledged by any response key, which triggered an additional 750 ms interval before the next trial sequence began.

Each person completed one practice block of 12 random trials followed by 576 experimental trials except for one person, who completed 563 experimental trials. This trial count corresponds with 4 randomly intermixed runs of all combinations of first target stimulus location (left, center or right), second target stimulus location (left, center or right), first target stimulus color (green or blue), second target stimulus color (green or blue), intervening event condition (present or absent) and cueing condition (predictive cue or no cue/all cued).

Participants were told to keep their eyes centered on fixation at all times and to respond quickly and accurately to the targets. Participants were also told that box brightening always preceded the appearance of the target stimuli and always predicted where the targets would appear. Thus, when there was only one box brightening, participants were told that they should attend to its location without making eye movements because it was the only possible target location. Otherwise, any location could contain the target.

RESULTS AND DISCUSSION

Only trials in which all keypress responses were correct were included in the RT analyses. Trials on which the second target appeared in peripheral and central vision were analyzed separately. We did this for three reasons: (1) to remain consistent with our previous analytical strategy (Hilchey et al., 2017), (2) to single out the central target condition, which best approximates the conditions for non-spatial IOR, and (3) practically, the levels of Location Repetition (see below) cannot be fully crossed for peripheral and central targets. As such, participant mean RTs for the second target stimulus on trials in which it appeared in peripheral vision were analyzed with a 3 (Location Repetition: repeat, switch peripheral [first target peripheral], switch central [first target central]) x 2 (Stimulus-Response Repetition: repeat or

switch) x 2 Intervening Event Condition (present or absent) x 2 (Location Cueing: predictive cue or no cue/all cued) repeated measures analysis of variance (ANOVA). Trials in which the second target stimulus appeared in central vision were analyzed in the same manner except Location Repetition did not contain the 'switch peripheral' condition.

Second target stimulus in peripheral vision

Most trials (95.1%) were completed without errors. Of these, a further 0.4% were excluded on account of unreasonably long (> 2 s) RTs, likely reflecting lapses of attention unrelated to the variables of interest. Z-scores for correct target RTs were computed for each participant. Trials (2.8%) with z-scores greater than 2.5 were excluded as outliers. Finally, we inspected the data for unreasonably long target (color) –target (color) onset asynchronies (TTOAs > 5s), leading to the exclusion of a further 0.5% of trials. The mean RTs to the first target and intervening event were 560 and 574 ms, respectively. This made the mean TTOAs 2.831 and 2.557 s for intervening event present and absent trials, respectively[1].

All of the mean RT data are illustrated in Figure 2A. The main effects of Location Cueing [$F(1, 19) = 134.20$, $MSE = 1306$, $p < 0.001$, $h^2 = 0.0729$] and Intervening Event Condition [$F(1, 19) = 7.22$, $MSE = 4263$, $p = 0.015$, $h^2 = 0.0146$] were significant. RTs were faster when the target location was known (498 ms vs 536 ms) and when there were not intervening events (509 vs 525 ms). The effect of Location Repetition was marginal [$F(2, 38) = 3.16$, $MSE = 929$, $p = 0.054$, $h^2 = 0.0026$], with a general tendency for faster RTs when target location repeated (~8 ms), and there was no reliable effect of Stimulus-Response Repetition [$F(1, 19) = 1.28$, $MSE = 1628$, $p = 0.272$].

There was a significant interaction between Location Repetition and Stimulus-Response Repetition [$F(2, 38) = 44.84$, $MSE = 1688$, $p < 0.001$, $h^2 = 0.0635$]. RTs were fastest when both the target location and response repeated or switched (see Figure 3A), which is the location-response repetition effect. There was also an interaction between Stimulus-Response Repetition and Intervening Event Condition [$F(1, 19) = 10.73$, $MSE = 1487$, $p = 0.004$, $h^2 = 0.0071$]. The

[1]We decided on a 1900-2100 ms response stimulus interval on trials without intervening events in order to roughly equate the TTOAs between trials with and without intervening response events, which obviously did not happen. We assumed, based on our prior work (Hilchey et al., 2017), that the *M* RT to the intervening response event would be roughly 300 ms. In those Experiments, there was always an intervening event. Here, where there was an intervening event on only half the trials, *M* RTs to the intervening event were almost double. This led to the CTOA being about 274 ms longer on trials with intervening events. This matter is discussed further in footnote 4.

intervening event diminished stimulus-response repetition effects, with a non-significant trend toward non-spatial IOR when there was an intervening response event (see Figure 4A). These were the only significant interactions (all other *p*s > 0.10).

Regarding the Location Cueing and Intervening Response Events, as they relate to the predictions for the repetition effects specifically, we first note simply that none of the interactions involving Location Cueing were significant. As shown in Figure 2A, location-response repetition effects were present regardless of whether there were predictive cues. As such, and as per usual, in the presence of location-response repetition effects, there is very little evidence of non-spatial or spatial IOR. This can be re-affirmed by looking specifically at the condition that would hypothetically unmask IOR, which is when there is both an intervening response event and a predictive cue (Figure 2A, top left quadrant). In this condition, there was a non-significant 4 ms overall RT cost for repeating a prior target [$t(19) = 0.824$, $p = 0.420$, 95%CI = -5.89 – 13.54 ms] and a significant 9 ms overall RT benefit for repeating a prior target location [$t(19) = 2.291$, $p = 0.034$, 95%CI = 0.78 – 17.36 ms], which would be the opposite of spatial IOR.

Finally, Stimulus-Response Repetition, Location Repetition and Intervening Response Event seemed to interact [$F(2, 38) = 2.426$, $MSE = 926$, $p = 0.102$, $h^2 = 0.0020$]. This slight trend occurred mainly because the location-response repetition effects were smaller than usual when there was an intervening response event. Regardless, under no circumstances was there any evidence of non-spatial IOR when target location repeated, as is apparent from all filled lines in Figure 2A. Nevertheless, as shown by the interaction between Intervening Response Event and Stimulus-Response Repetition, the intervening response event nullified the stimulus-response repetition effect (see Figure 4A). As for spatial IOR, there was no trace of it in any of the four possible combinations of Intervening Response Event and Location Cueing. Collapsing across stimulus-response repetition, RTs were always slightly faster overall when target location repeated.

A meaningful corresponding analysis of error rates was made impossible by near-ceiling performance to the second target stimulus in many conditions (97.7% accuracy overall). 350 of 480 cells in the full design, factoring in the number of participants, did not contain any errors and 7/20 participants made no more than 5 errors to this target across all trials of the experiment. Indeed, 20 of the 24 (i.e., 3 x 2 x 2 x 2) cells in the experiment contained fewer than 10 total

errors. The four that contained more than 10 total errors were those on which the target location repeated and the response switched or the target location switched and the response repeated, without a predictive cue. Note, however, that even in these cases only a select few participants contributed errors.

Second target stimulus in central vision

Most trials (95.2%) were again completed without errors. Of these, a further 0.7% were excluded because of exceptionally long RTs (> 2 s). Trials (2.8%) with z-scores greater than 2.5 were excluded. Unreasonably long TTOAs (> 5s) led to the exclusion of 0.4% of the trials. The mean RTs to the first target stimulus and intervening event were 558 and 575 ms.

All of the mean RT data are illustrated in Figure 2B. All main effects were significant. Mean RTs were faster when: (1) target location was known (510 ms) relative to unknown (526 ms) [$F(1, 19) = 10.99$, $MSE = 2189$, $p = 0.003$, $h^2 = 0.0152$], (2) target location repeated (507 ms) relative to switched (524 ms) [$F(1, 19) = 10.67$, $MSE = 1866$, $p = 0.004$, $h^2 = 0.0125$], (3) the stimulus repeated (513 ms) relative to switched (523 ms) [$F(1, 19) = 9.64$, $MSE = 1706$, $p = 0.006$, $h^2 = 0.0104$, (4) the intervening event was absent (507 ms) relative to present (530 ms) [$F(1, 19) = 9.01$, $MSE = 5896$, $p = 0.007$, $h^2 = 0.0329$].

The same two-way interactions that were observed for peripheral targets were observed for central targets. Location Repetition interacted with Stimulus-Response Repetition [$F(1, 19) = 12.48$, $MSE = 1596$, $p = 0.002$, $h^2 = 0.0125$], reflecting a location-response repetition effect. Here though, RTs were particularly fast when both target location and response repeated but not when both target location and response switched (see Figure 3B; see also *Follow-up analysis*). Also, Intervening Event Condition interacted with Stimulus-Response Repetition [$F(1, 19) = 6.66$, $MSE = 1893$, $p = 0.018$, $h^2 = 0.0079$], reflecting diminished stimulus-response repetition effects with intervening events (see Figure 4B).

Regarding the Location Cueing and Intervening Response Event conditions as they relate to the repetition effects, the findings parallel the observations from the previous section. As before, none of the interactions involving Location Cueing were significant (all ps > .10)[2]. As

[2] An anonymous reviewer suggested that it would be interesting to examine whether Location Cueing altered inter-trial priming effects. That is, would the predictive cue alter the repetition effects from trial n-1 to trial n, as measured by the RT to the first target stimulus on trial n? Note a few things. The inter-trial interval consisted of a 750 ms black screen. Trial sequences were excluded if errors were made on trial n-1 or if the first target on trial n contained

shown in Figure 2B, there were location-response repetition effects regardless of whether there were predictive cues. As per usual then, there was little evidence of non-spatial or spatial IOR. Again, this can be re-affirmed by looking specifically at the condition that would hypothetically unmask IOR, which is when there is both an intervening response event and a predictive cue (Figure 2B, top left quadrant). There was a non-significant 3 ms overall benefit for repeating the prior target [$t(19) = 0.345$, $p = 0.734$, 95%CI = -17.79 – 12.76 ms]. There was a significant 16 ms overall benefit for repeating the prior target location [$t(19) = 3.188$, $p = 0.005$, 95%CI = 5.62 – 27.62 ms], which is the opposite of spatial IOR,

Similar to the peripheral target findings, here too it seemed that the intervening response events may have diminished the location-response repetition effects [$F(1, 19) = 2.78$, $MSE = 1254$, $p = 0.112$, $h^2 = 0.0023$]. Even still, there was no obvious evidence of spatial or non-spatial IOR in any of the conditions, even when the location-response repetition effects were least pronounced (see Figure 2B, left column). Nevertheless, as revealed by the interaction between Intervening Response Event and Stimulus-Response Repetition, the intervening response event nullified the stimulus-response repetition effect.

Again, accuracy for the second target stimulus were too high (98.1%) to conduct formal statistical analyses; 261 of 320 cells, factoring in the participants, did not contain errors. All 16 experimental cells (2 x 2 x 2 x 2) contained 12 or fewer total errors, with 12 cells containing five or fewer total errors.

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an error. Note further that trial n-1 and n could have been precued or not. As per usual, RTs > 2 s were first excluded and z-scores > 2.5 for the first target on trial n were excluded as outliers. To increase power, we pooled the central and peripheral target data and conducted a 4-way repeated measures ANOVA with the following factors: Location Repetition (repeat or switch) x Stimulus-Response Repetition (repeat or switch) x n-1 Location Cueing (predictive or no cue) x n Location Cueing (predictive or no cue). N Location Cueing was significant, with faster RTs (~24 ms) when the target location was predicted [$F(1, 19) = 30.2$, MSE = 1395, $p < 0.001$, $h^2 = 0.0301$] but n Location Cueing did not interact with anything (all ps > .24). There was a main effect of Stimulus-Response Repetition [$F(1, 19) = 12.81$, $MSE = 1277$, $p = 0.002$, $h^2 = 0.0119$], with generally faster (~15 ms) RTs for stimulus-response repetitions than switches. The main effect of Location Repetition was marginal [$F(1, 19) = 3.982$, $MSE = 508$, $p = 0.061$, , $h^2 = 0.0014$], with generally faster RTs (~5 ms) for location repetitions than alternations. As per usual, Location Repetition and Stimulus-Response Repetition interacted [$F(1, 19) = 20.59$, $MSE = 671$, $p < 0.001$, $h^2 = 0.0108$], reflecting the location-response repetition effect. Nothing else was reliable (all ps > .10). Note further that n Location Cueing does not reliably interact with these repetition effects even if we (1) ignore whether trial n-1 contained a predictive cue or (2) analyze whether the first target on trial n appeared in central or peripheral vision separately.

Follow-up analysis

Informal examination of the central and peripheral target data suggests that the interaction between Stimulus-Response Repetition and Location Repetition was weaker for central than peripheral targets. This apparent difference was beyond our purview; but given that we have observed it three times now (see also Experiments 1 and 2 in Hilchey et al., 2017), we decided to take a closer look. Furthermore, as previously noted, it seemed as though the intervening event, despite not revealing much clear evidence of IOR, reduced the location-response repetition effects. While there may be a three-way interaction among these factors, it must be subtle given that intervening events do not dramatically alter location-response repetition effects (Hilchey et al., 2017).

To take a closer look, the data were collapsed across Location Cueing, which did not interact with anything, and re-analyzed with the factors Location Repetition (same or different[3]), Stimulus-Response Repetition (same or different), Intervening Event (present or absent) plus a new factor, Second Target Location (central or peripheral). All of the mean RT data are illustrated in Figure 5. There were effects of Location Repetition [$F(1, 19) = 16.21$, $MSE = 695$, $p < 0.001$, $h^2 = 0.0083$] and Stimulus-Response Repetition [$F(1, 19) = 15.73$, $MSE = 1232$, $p < 0.001$, $h^2 = 0.0141$], with faster RTs for repeated as compared to switched target locations and features, respectively. Also, intervening events slowed down RTs [$F(1, 19) = 9.483$, $MSE = 3552$, $p = 0.006$, $h^2 = 0.0244$]. There was no main effect of Second Target Location ($F < 1$).

As already shown, Location Repetition and Stimulus-Response Repetition interacted [$F(1, 19) = 47.19$, $MSE = 1146$, $p < 0.001$, $h^2 = 0.0386$], and so too did Stimulus-Response Repetition and Intervening Event Condition [$F(1, 19) = 11.66$, $MSE = 1108$, $p = 0.003$, $h^2 = 0.0095$]. None of the other two-way interactions were significant (ps > 0.10).

Of greater interest is the interaction among Location Repetition, Stimulus-Response Repetition and Second Target Location, which was significant [$F(1, 19) = 22.47$, $MSE = 384$, $p < 0.001$, $h^2 = 0.0064$]. Location-response repetition effects were larger for peripheral than central targets, perhaps in part because for peripheral, but not central, targets, there was also an RT advantage for switching both the prior target location and response (see Figure 5). Finally, the

[3] 'Switch' collapses across the levels 'switch central' and 'switch peripheral' because it is not possible for a second central target stimulus to mismatch the first target stimulus at the level of 'switch central' but also because these two conditions typically yield similar RT effects. Note that all of the reported effects are significant even if 'switch central' trials are removed from the analysis.

interaction among Location Repetition, Stimulus-Response Repetition and Intervening Event Condition was significant [$F(1, 19) = 6.47$, $MSE = 493$, $p = 0.0198$, $h^2 = 0.0024$]. Simply, location-response repetition effects were smaller with intervening response events (see Figure 5)[4]. None of the other higher order interactions were significant (Fs < 1).

GENERAL DISCUSSION

Our primary objective was to determine whether increasing target location certainty to 100% with a valid precue would abolish location-response repetition effects, thereby unmasking any latent stimulus-only or location-only repetition effects (e.g., non-spatial or spatial IOR) brought on by the intervening response event. Although perfectly valid target location cues clearly improved performance, presumably by focusing attention on the target location in advance of its appearance, there was no discernible impact of target location foreknowledge on the stimulus-response or location-response repetition effects, or any others for that matter. In contrast, intervening response events reduced stimulus-response repetition effects and, more subtly, location-response repetition effects. Finally, we confirmed serendipitously that location-response repetition effects were more robust for peripheral than central targets.

The impetus for this study harkens back to an unsolved puzzle from the turn of the twenty-first century: why are non-spatial and spatial IOR so difficult to find in tasks involving multiple possible target locations and arbitrary, manual responses to stimulus shapes or colors? A plausible explanation was that recently established links between locations and their responses are relied upon more heavily when target location is ambiguous. Thus, we figured that by making target location certain, in combination with the intervening response event, we could

[4] The interactions involving the Intervening Event Condition are obviously confounded by longer TTOAs when there are intervening events. Nevertheless, it seems reasonably clear that the intervening event, not the TTOA difference, is mainly responsible for the interactions. First, regarding the interaction between Intervening Event and Stimulus-Response repetition, Spadaro, He and Milliken (2012; Experiment 1A) have already shown normal RT advantages for stimulus-response repetition without intervening events at TTOAs of about 2 and 3 s and disadvantages for stimulus-response repetition with intervening events also at TTOAs of about 2 and 3 s. Second, we re-analyzed the data in the "Follow-up analysis", except we only included intervening event trials with 800 ms (not 1000 ms) intervals between the first target stimulus and intervening event and we only included non-intervening event trials with response stimulus intervals of 2100 ms. Thus, the TTOAs for trials with and without intervening events were on average within about one tenth of a second of one other. Furthermore, we collapsed across Second Target Stimulus Location because this did not interact with the Intervening Event Condition. The interaction between Intervening Event and Stimulus-Response Repetition [$F(1, 19) = 5.67$, $MSE = 529$, $p = 0.0279$, $h^2 = 0.0047$] and the interaction among Intervening Event, Stimulus-Response Repetition, and Location Repetition [$F(1, 19) = 10.14$, $MSE = 292$, $p = 0.005$, $h^2 = 0.0047$] remained significant.

abolish any location-response repetition effects, thereby unmasking attentional priming effects, be it spatial or non-spatial IOR. This notion, at least in this context, appears mostly wrong, given that there was virtually no clear evidence of IOR in any of the conditions.

If it is not target location uncertainty that leads to the location-response repetition effects that mask IOR, what does? It seems increasingly likely that the mere presence of multiple possible target locations in peripheral vision, at least in the context of arbitrary manual responding, leads to location-response repetition effects that can completely overshadow hypothetical non-spatial and spatial IOR effects. A hypothesis is that these location-response repetition effects, which are often independent of stimulus-response repetition effects (e.g., Hommel, 1998; Hommel, 2005; Hilchey et al., in 2017), are weighted more heavily when there is more than one possible target location (cf. the present study and Spadaro et al., 2012) and more than one possible manual response (cf. the present study and Wilson et al., 2006; discussed more below), and when the task involves arbitrary discrimination responses (e.g., Tanaka & Shimojo, 2000; Taylor & Donnelley, 2002). Obviously, on the basis of the present data and our prior findings, we are much more confident that there is considerable independence between location-response repetition effects, stimulus-response repetition effects and spatial attention (see Hommel, 2011; Colzato & Hommel, 2004, for additional considerations). That being said, it remains theoretically possible that a unique combination of expectancies for location, stimulus and response repetitions would modulate the effect of the prior location response on the current one (Kingstone, 1992), lest these effects occur automatically within the context of the task (Hommel, Memelink, Zmigrod & Colzato, 2014).

While reducing target location ambiguity did not matter for the repetition effects in the present study, the presence of an intervening response event did. On the one hand, the effect of the intervening event on the location-response effect was subtle; it became a little smaller, without revealing any evidence of spatial IOR. On the other hand, the intervening response events clearly reduced stimulus-response repetition effects, findings that are at least halfway consistent with Spadaro et al., (2012)'s findings. However, while Spadaro et al. were able to show RT costs for repeated stimuli at fixation across eight different experiments, we have never been able to show this in our tasks, which involve more than one possible target location (see all of our "same" location lines in Figures 2 and 5) and persistent location-response repetition effects.

Location-response repetition effects were larger for peripheral than central targets, which accords with our earlier findings (Hilchey et al., 2017). Although unanticipated, this finding provides clues about the nature of location-response repetition effects in 2-AFC tasks involving arbitrary manual responses to colors or shapes. As noted by Hommel, Proctor and Vu (2004), although target locations are, for all intents and purposes, irrelevant in such tasks, these tasks do introduce correspondences between the lateralized target locations and lateralized manual responses. It is conceivable that, in the context of lateralized manual responding, lateralized target locations afford a more effective retrieval cue of the prior location-response code than a stimulus in central vision. If there is merit to this notion, we would expect location-response repetition effects to break down or become smaller in these tasks when the response set is not spatially-defined (e.g., Hommel, 2007; Hommel, 2011). Similarly, it is possible that adding a third response to this task, such that central targets accord more obviously with a response, would bolster the location-response effects at fixation, so that they more closely resemble what is observed for peripheral targets. Thus, whereas spatially-defined responses mediate location repetition effects in standard 2-AFC tasks, these location-response repetition effects may disappear with responses that are not spatially-defined (e.g., vocal), which could clarify what target location repetition looks like independent of the relationships between stimulus and response location.

The present findings also have some implications for the spatial IOR literature. Spatial IOR, as an attentional bias against previously attended locations, is simply not needed to account for extant manual RT data in discrimination tasks. This is not to say that spatial IOR does or does not exist in these tasks. As already noted, spatial IOR could be completely obscured by response-related repetition heuristics (see also, e.g., Christie & Klein, 2001) but the data do not yet necessitate the involvement of processes above and beyond those hypothetically involved in the location-response repetition heuristics. Complementing the present findings is a study by Wilson, Castel and Pratt (2006), who administered a color-based go no-go task, which required a single keypress response for go stimuli and no response for no-go stimuli. The general structure of their paradigm is different from the present in that there is only one response finger and responses must be withheld to select target colors (no-go stimuli). The crucial finding from that study was that whenever a go stimulus was preceded by another go stimulus, there was no effect of repeating the prior target location, regardless of whether the go stimuli were the same color.

Now, when the go stimulus was preceded by a no-go stimulus, RTs were slowest if the two stimuli appeared at the same location. This may or may not be spatial IOR in the sense intended by Posner, mainly because IOR is not confined to the location of an ignored stimulus (e.g., Vaughan, 1984; Posner et al., 1984; Maylor & Hockey, 1985; Posner, Rafal, Choate & Vaughan, 1985).

The findings obtained by Wilson et al (2006) and the current study are alternatively accounted for by the Theory of Event Coding (TEC; Hommel, Musseler, Aschersleben, & Prinz, 2001; Hommel, 2004), an implicit memory retrieval and updating framework, without assuming effects on attention (see also, e.g., Lupianez, Martin-Arevalo & Chica, 2013). Target location repetition costs in simple color and shape 2-AFC tasks with arbitrary manual responses are expected whenever the prior location response (or lack thereof) mismatches the current location response but, all else as equal, not otherwise. We are unaware of any 2-AFC tasks, with arbitrary responses to shapes or colors, that clearly demonstrate spatial IOR when all aspects of the cue event, including the response, repeat as the target event. Until this can be clearly demonstrated – that is, until the location-response repetition heuristics obscuring IOR can be knocked out or altered independent of IOR – it will remain unclear from the manual RT data whether spatial IOR is concealed by location-response repetition effects.

Finally, we contemplate the relevance of these findings in the context of the inter-trial priming literature, which embeds a target among distractors, and from which we developed some confidence in the target location uncertainty hypothesis. The 'dual-stage' account (Lamy, Yashar & Ruderman, 2010) for inter-trial priming in visual search asserts that response repetition tendencies, as a result of repeating a prior search-defining feature (e.g., color), are more likely in difficult search tasks (see also, e.g., Asgeirsson & Kristjansson, 2011), perhaps reflecting some sort of stimulus-response repetition heuristic (Lamy, Zivony & Yashar, 2011; Yashar & Lamy, 2011). This point indeed accounts well for whether repetition of the search-defining feature interacts with the repetition of responding across trials in visual search. Granted, color and response repetition can interact without distractors in discrimination tasks, even if color is not the response-defining attribute, but this is usually the exception and not the rule (Hommel, 1998; Colzato & Hommel, 2004).

The story must be quite different for location-response repetition effects. This is because location-response effects are substantial even when the target location is precued and the target

itself is unaccompanied by distractors. With distractors in the display, it is somewhat difficult to assess the robustness of the location-response repetition effect, mainly because studies looking at target location repetition do not often analyze response repetition (e.g., Maljkovic & Nakayama, 1996; Kumada & Humphreys, 2002; Kristjansson, Vuilleumeir, Malhotra, Husain & Driver, 2005; Geyer, Müller, & Krummenacher, 2007; Geyer, Zehetleitner & Müller, 2010; Yashar & Lamy, 2010; Tower-Richardi, Leber & Golomb, 2016). However, Hermann Müller's group has taken some interest in location-response repetition effects (e.g., Krummenacher, Müller, Zehetleitner, & Geyer, 2009; Gokce, Müller & Geyer, 2013; Gokce, Geyer, Finke, Müller & Tollner, 2014), demonstrating that they are reliable in the context of a variety of 2-AFC tasks with distractors. These findings sometimes challenge whether target location repetition leads to positive attentional priming effects (Gokce et al., 2014; but see, e.g., Asgeirsson, Kristjansson & Bundesen, 2014, with a different approach). For example, Gokce et al (2014) tentatively suggest, on the basis of an electrophysiological index (i.e., the posterior contralateral positivity), that early sensory encoding may be suppressed when two targets appear at the same location, which is at least partly consistent with the RT data from a number of early studies requiring simple detection and localization responses (e.g., Tanaka & Shimojo, 1996; Tanaka & Shimojo, 2000; Bichot & Schall, 2002; but see, e.g., Campana & Casco, 2009; Yashar & Lamy, 2010). Despite this, and in general, the exact boundaries on the location-response repetition effects remain fuzzy. None of this is to deny attentional spatial priming effects in the inter-trial priming literature on visual search, whether positive or negative; simply, these attentional effects are likely co-occurring with substantial location-response repetition effects when relatively arbitrary manual responses to shapes or colors are involved.

For now, it is clear that location-response repetition effects contribute significantly to the repetition effects in typical attention priming studies with arbitrary manual discrimination responses and, thus, cannot be ignored. This study makes clear that these location-response repetition effects are not easily disrupted by intervening response events and are not abolished or reduced by increasing target location certainty, all things being equal. Indeed, the absence of any interactions involving attentional orienting cues, which served to reduce target location ambiguity, along with all of the repetition effects here, casts doubt on whether any repetition effects found in this paradigm, without distractors, have much to do with attentional orienting. If the repetition effects had something to do with attentional orienting, the expectation is that the

cues would have altered at least one of them. For example, independent of the location-response repetition effects, pre-cueing the target location might have been expected to reduce any stimulus-only or location-only repetition related to attentional orienting, much like it reduces positive feature-based attentional priming (Goolsby & Suzuki, 2001) and dimension-based attentional priming (Zehetleitner et al., 2012) across trials in visual search tasks (i.e., with distractors). Instead, the repetition effects from typical non-spatial 2-AFC tasks without distractors appear to depend primarily on implicit response repetition heuristics linked to the prior stimulus location, which may overshadow attentional priming effects on theoretical grounds, but this is proving difficult to establish empirically.

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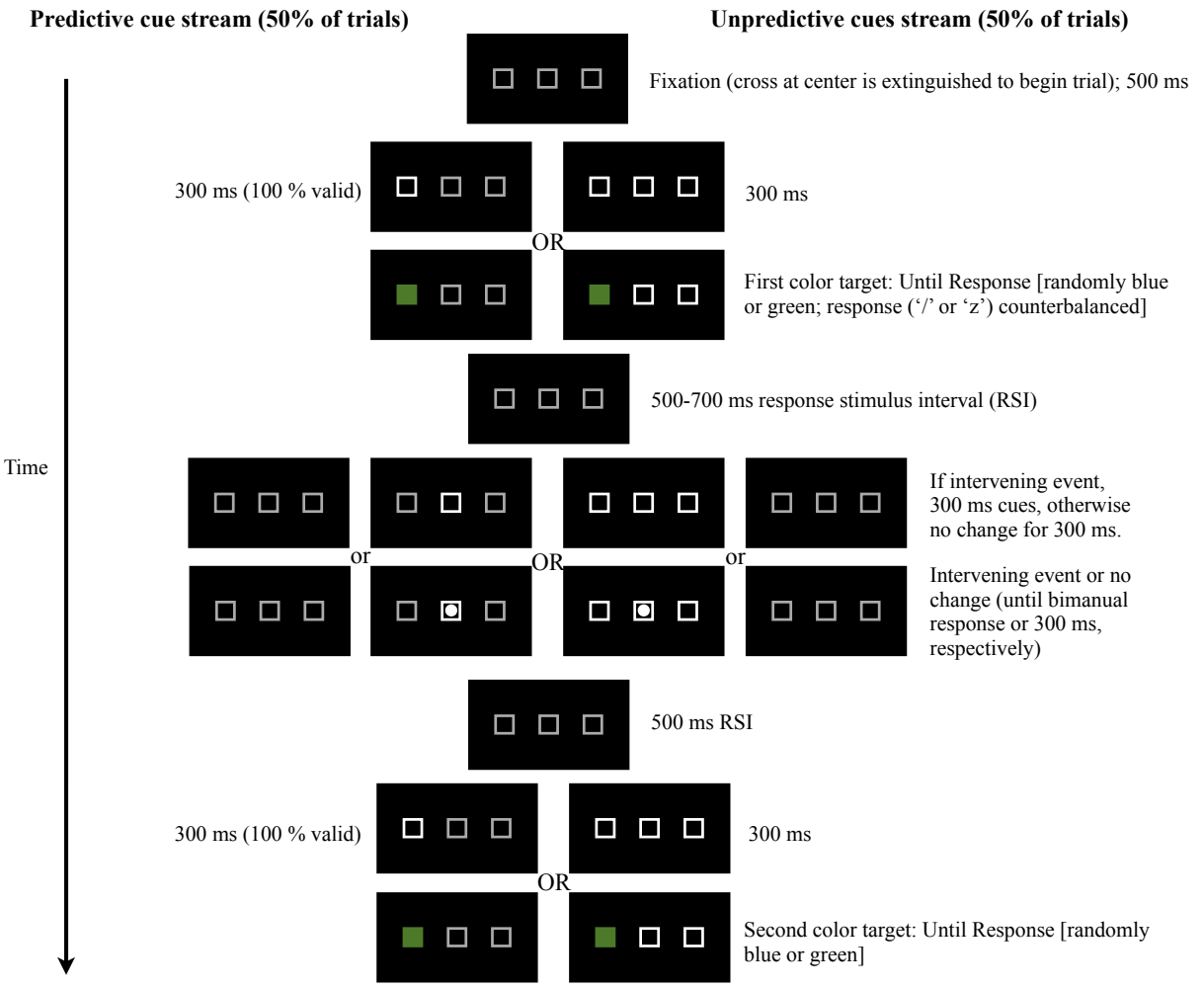

Figure 1. Possible event sequences in any given trial. The color targets appear at random marked locations in the unpredictive cues stream (right) whereas the color targets appear at the lone pre-cued location in the predictive cues stream (left).

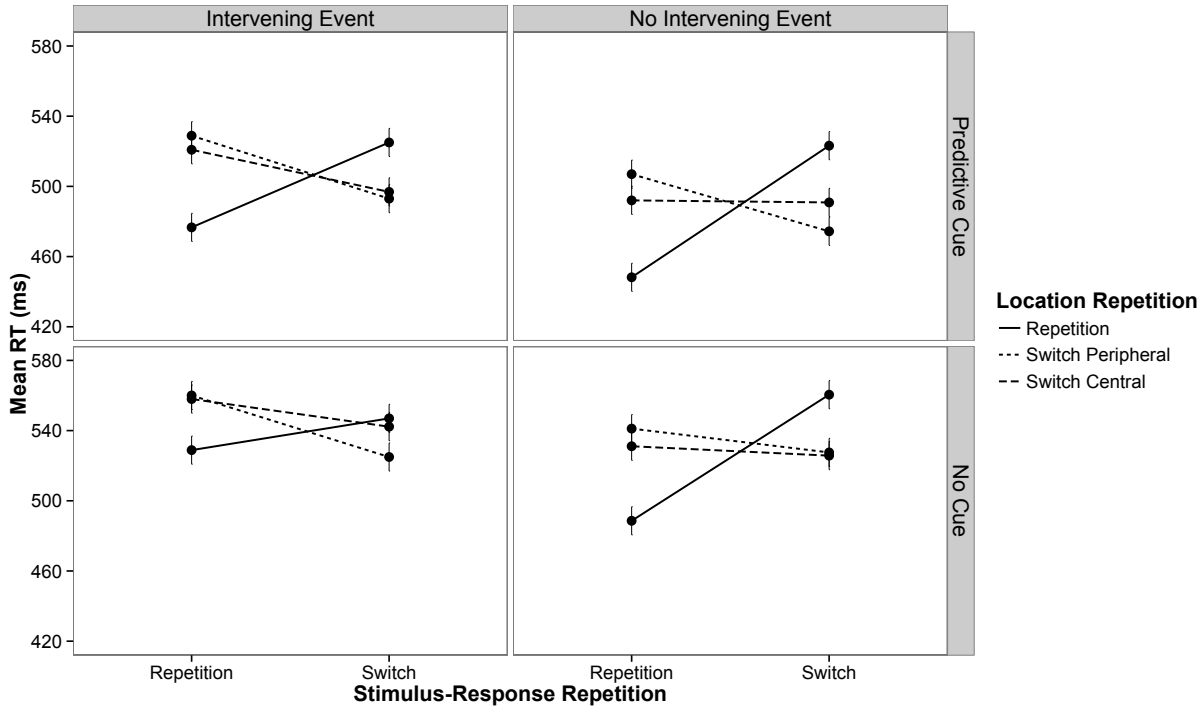

Figure 2A. Mean reactions times (RTs) for all combinations of Intervening Event Condition (columns), Location Cueing (rows), Stimulus-Response Repetition (x-axis) and Location Repetition (line type) when the second target color appeared in peripheral vision. Error bars are half Fisher Least Significant Differences computed from the mean squared errors of the four-way interaction. Non-overlap signifies a significant effect.

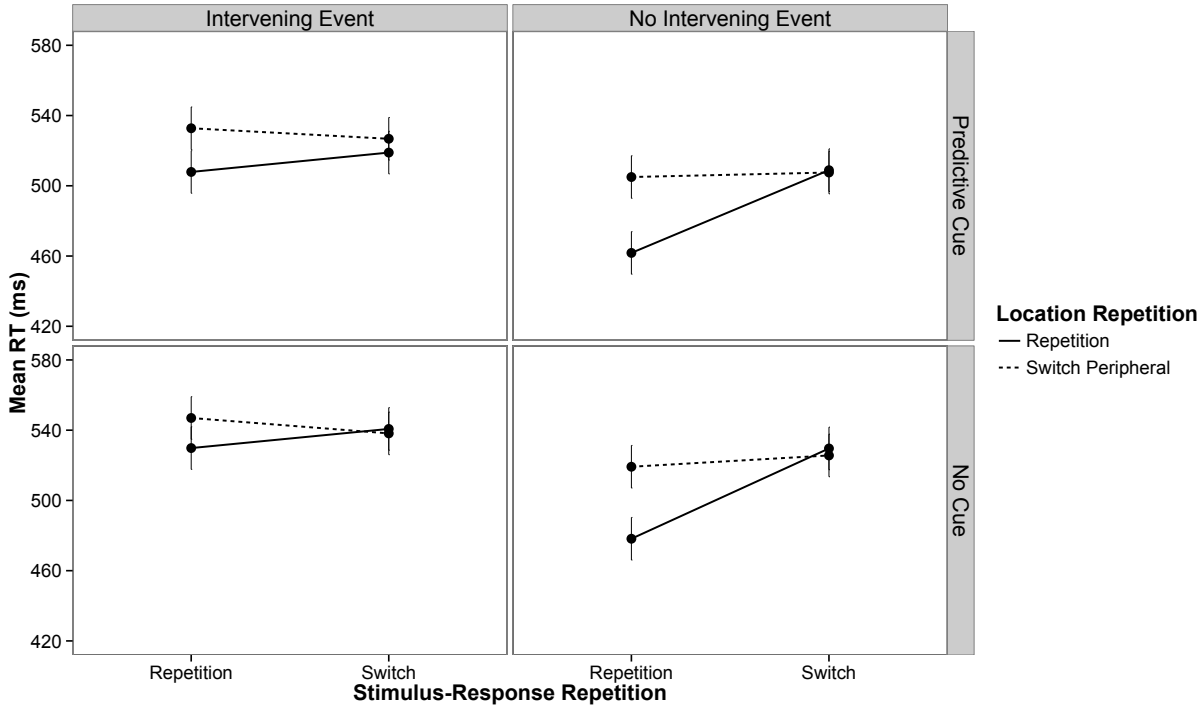

Figure 2B. Mean reactions times (RTs) for all combinations of Intervening Event Condition (columns), Location Cueing (rows), Stimulus-Response Repetition (x-axis) and Location Repetition (line type) when the second target color appeared in central vision. Error bars are half Fisher Least Significant Differences computed from the mean squared error of the four-way interaction.

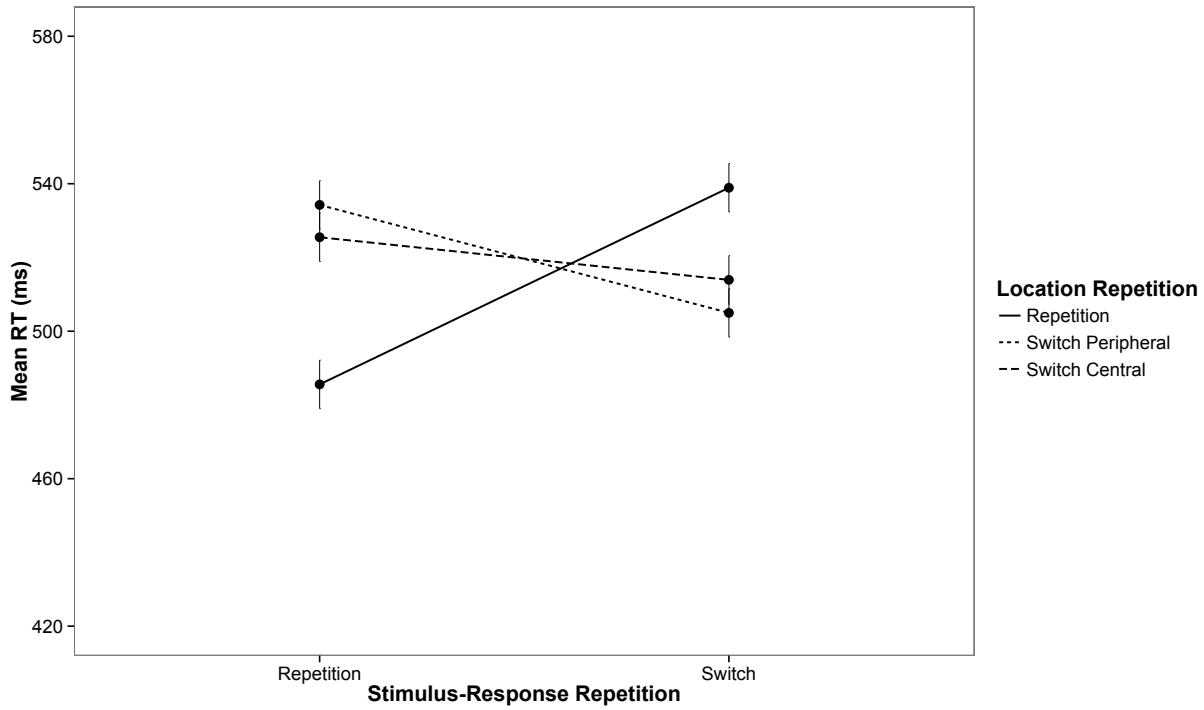

Figure 3A. Mean reaction times (RTs) for the interaction between Stimulus-Response Repetition (x-axis) and Location Repetition (line type), collapsing across Intervening Event Condition and Location Cueing, when the second target color appeared in peripheral vision. Error bars are half Fisher's Least Significant Differences computed from the mean squared error of the interaction.

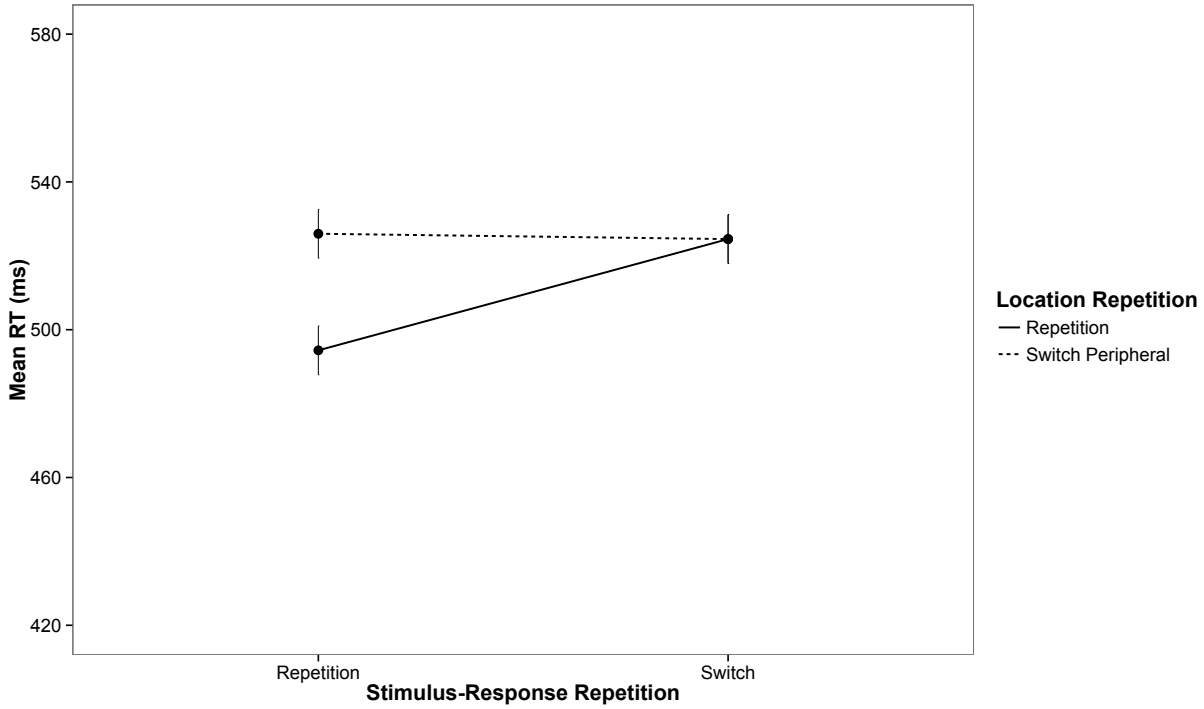

Figure 3B. Mean reaction times (RTs) for the interaction between Stimulus-Response Repetition (x-axis) and Location Repetition (line type), collapsing across Intervening Event Condition and Location Cueing, when the second target color appeared in central vision. Error bars are half Fisher's Least Significant Differences computed from the mean squared error of the interaction.

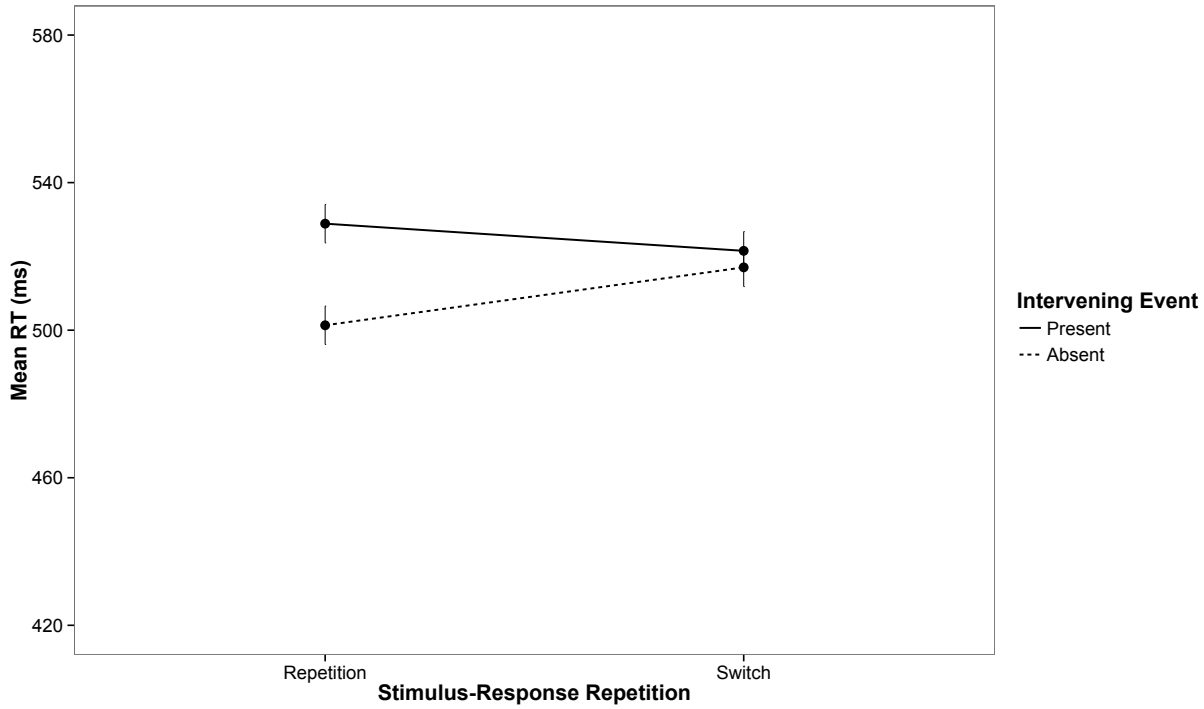

Figure 4A. Mean reaction times (RTs) for the interaction between Stimulus-Response Repetition (x-axis) and Intervening Event Condition (line type), collapsing across Location Repetition and Location Cueing, when the second color target stimulus in a trial appeared in peripheral vision. Error bars are half Fisher's Least Significant Differences computed from the mean squared error of the interaction.

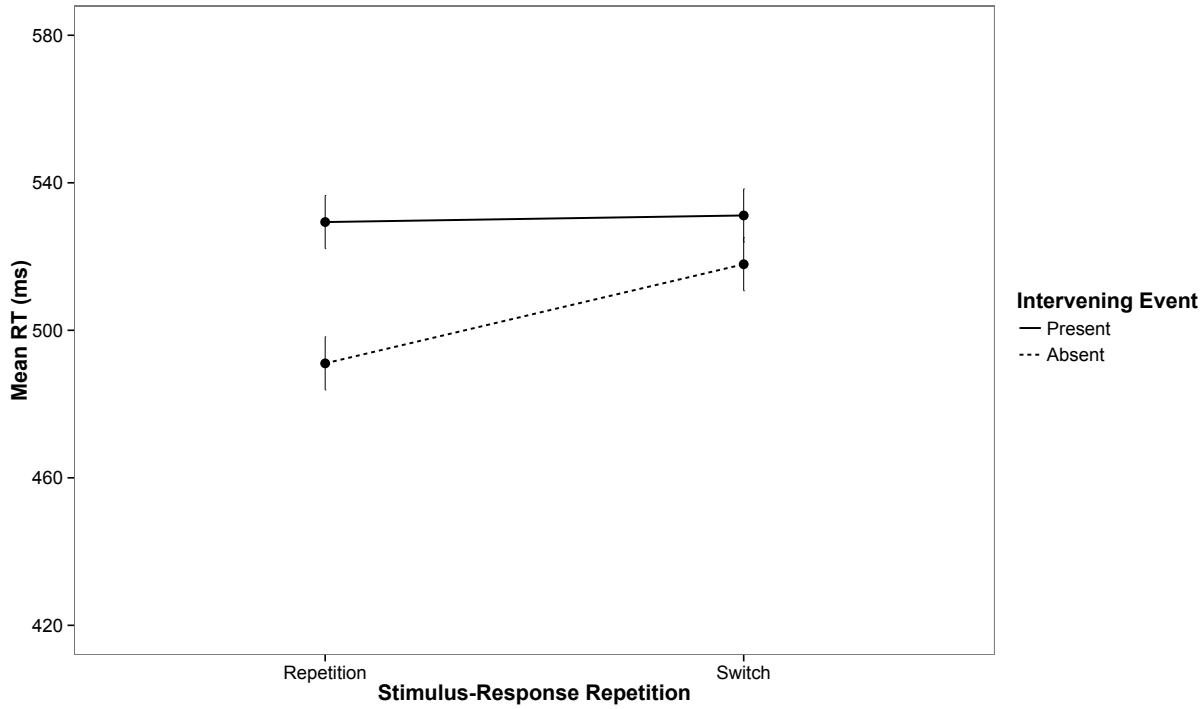

Figure 4B. Mean reaction times (RTs) for the interaction between Stimulus-Response Repetition (x-axis) and Intervening Event Condition (line type), collapsing across Location Repetition and Location Cueing, when the second color target stimulus in a trial appeared in central vision. Error bars are half Fisher's Least Significant Differences computed from the mean squared error of the interaction.

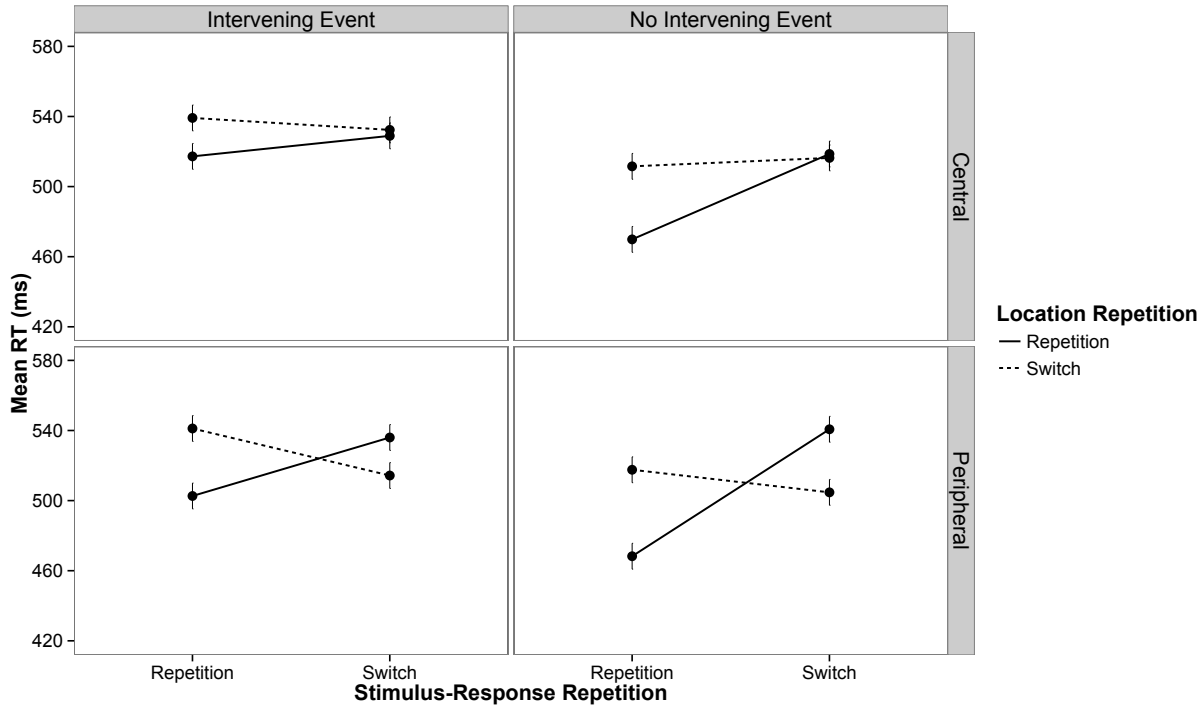

Figure 5. Mean reactions times (RTs) for all combinations of Intervening Event Condition (columns), Second Target Location (rows), Stimulus-Response Repetition (x-axis) and Location Repetition (line type), collapsing across Target Location Cueing. The error bars are half Fisher Least Significant Differences computed from the mean squared error of the four-way interaction.